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The existence of dolphin groups in the direct care of humans is a recent development on a world-wide basis. In the past 30 years, much progress has been made in understanding cetacean biology through study of delphinids in human care. Millions of people who otherwise would have no proximate experience with these sea mammals have appreciated and learned about them. Further, dolphins have become a symbol and a vehicle for educating the public on the world's oceans and their ecosystems. Protection of ocean ecosystems must be a high priority as we look toward the 21st century. At the top of the ocean food chain, delphinids may be important indicator species for understanding the effects of some human activities on the ocean environment.

Progress must continue in all of cetacean biology. In my specialties, delphinid clinical medicine and neurobiology, there are exciting prospects. We can enhance the condition and extend the life-span of dolphins in our care. Preventive medicine, improved disease treatment through better medications such as new antibiotics, and improved methods such as anaesthesia and surgery should be more widely practiced. Progress in anatomy, molecular biology, physiology, and cognitive neuroscience should give us new insight on the delphinid brain, one of the more challenging objects of our time.

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# 人間とイルカ：今後の獣医学的研究課題

サム H. リッジウェイ

# DOLPHINS IN THE CARE OF HUMANS: A LOOK TOWARD THE FUTURE

SAM H. RIDGWAY*[1]


## ABSTRACT

The exsistence of dolphin groups in the direct care of humans is a recent development on a world-wide basis. In the past 30 years, much progress has been made in understanding cetacean biology through study of delphinids in human care. Millions of people who otherwise would have no proximate experience with these sea mammals have appreciated and learned about them. Further, dolphins have become a symbol and a vehicle for educating the public on the world's oceans and their ecosystems. Protection of ocean ecosystems must be a high priority as we look toward the 21st century. At the top of the ocean food chain, delphinids may be important indicator species for understanding the effects of some human activities on the ocean environment.

Progress must continue in all of cetacean ogy. In my specialties, delphinid clinical medicine and neurobiology, there are exciting prospects. We can enhance the condition and extend the life-span of dolphins in our care. Preventive medicine, improved disease treatment through better medications such as new antibiotics, and improved methods such as anesthesia and surgery should be more widely practiced. Progress in anatomy, molecular biology, physiology, and cognitive neuroscience should give us new insight on the delphinid brain, one of the more challenging objects of our time.


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Through study of delphinids in human care over the past 30 years, much progress has been made in understanding cetacean biology. Millions of people over the world who would otherwise have no proximate experience with sea mammals, have appreciated and learned about dolphins in their visits to zoos, marine parks, and aquaria; in the United States alone, 112 million people visited such establishments in 1991. Through such contacts, dolphins have become symbols of the world's ocean ecosystems and vehicles for educating the public about environmental protection. More specifically, delphinids, since they are at the top of the ocean food chain, may be important indicator species for understanding the effects of some human activities on the ocean environment. Protection of ocean ecosystems must be a high priority as we look toward the 21st century.

Progress must continue in all areas of cetacean biology. In my specialties, delphinid clinical medicine and neurobiology (Ridgway, 1990).

There are exciting prospects. In addition to general concerns such as preventive medicine, improved disease treatment, pharmacological applications, and improved methods such as anesthesia and surgery, I expect to see marked progress in our knowledge of delphinid anatomy, molecular biology, physiology, and cognitive neuroscience. All of these disciplines will provide new insight into the delphinid brain, as one of the more challenging studies of our time.

The dolphin brain is large and even more convoluted than the human brain; the dolphin brain has about one-third more surface area. But, because the dolphin cerebral cortex is, on the average, thinner than the human cortex, the dolphin brain has only about 80% as much cortex as the human brain (Ridgway and Brownson, 1984; Ridgway, 1990). The extra size of dolphin brains is devoted more to white matter than to gray. When the dolphin brain is bisected, the medial view (Fig. 1) of the cerebral hemisphere shows the large area called the parahyppocampal lobe, an area which has no recognized equivalent in the brains of humans and other land mammals. Also seen on the medial surface of the hemisphere is the corpus callosum; this great bundle of nerve fibers that connects the two cerebral hemispheres, is small relative to the size of the dolphin brain. The dolphin corpus callosum is only about 30% as large as the human corpus callosum, a fact that suggests the possibility that the two hemispheres of the dolphin brain may act more independently.

Hemispheric independence may also be reflected at the level of the optic chiasm. Fig. 2 shows the ventral surface of a brain from a dolphin that was blind in the left eye. Note that the left optic nerve and the right optic tract are clear, devoid of the milk-white myelin that is present in the other optic nerve and tract. The clear nerve and tract are evidence that the myelinated optic nerve fibers from the blind left eye have degenerated. This illustrates that all visual input from the right eye goes to the left hemisphere of the brain and vice versa. This condition differs from that of humans and of most other mammals in which at least some fibers from each eye pass to each cerebral hemisphere (Jaqcobs *et al.*, 1975; Tarpley *et al.*, 1992).

In a thorough post-mortem examination, the brain should always be inspected because it may contain important pathology. For example, I have found large areas of cerebral and cerebellar necrosis with fluke ova in the brains of stranded dolphins (Ridgway and Dailey, 1972).

One of the brain's major sensory organs is the skin. Therefore, we should pay close attention to skin analysis. The skin is an important sense organ, an immune defense organ, and a metabolic organ and, as such, creates a multifold protective barrier against numerous environmental insults. Although a dolphin's skin feels smooth to the touch, a magnified photograph of the skin surface of the bottlenose dolphin, *Tursiops truncatus*, shows that it is not entirely smooth; the surface contains many ridges, much like human fingerprint skin (Fig. 3). Over most of the forward half of the body from about the eyes and blowhole to the dorsal fin, the ridges are oriented perpendicular to (at a right angle to) the body axis. A section taken in line with the body axis, carefully prepared without distortion and viewed under a microscope, shows that there are 20 to 25 ridges per cm. Dolphin skin is sensitive and contains many nerve endings (Harrison and Thurley, 1972; Kolchin and Bel'kovich, 1973; Ridgway and Carder, 1990). The ridges may increase the dolphin's skin sensitivity relative to the number of nerve endings in the skin and, perhaps, may improvde its hydrodynamic characteristcs (Shoemaker and Ridgway, 1991; Ridgway and Carder, 1990). The white whale, *Delphinapterus leucas*, has similar skin ridges; however, the ridges are much larger than those of other delphinids that I have examined.

Like bottlenose dolphins, white whales are also surprisingly good divers. A trained whale made dives as deep as 647m in the open ocean

(Ridgway *et al.*, 1984; Ridgway, 1986). Pacific bottlenose dolphins have been trained to dive to depths of over 500m. Such animals trained to cooperate in experiments and trained to cooperate in their own medical care help us learn more about their physiological function. Modern husbandry programs incorporate a routine of trained behaviors that allow for health evaluation without the stress that could be involved in the capture and restraint of an untrained animal. Behaviors for medical examination may include open-mouth presentation for examination and manipulation, fluke presentation for blood collection, eye presentation for photographic examination or medication, stationing for temperature probe insertion or fecal sampling, and general acceptance of human manipulation for facilitating examination of the entire body. For temperature measurement of a white whale, I insert the probe 50cm into the anus; of a bottlenose dolphin, 25cm. Standard depths must be used because, if a probe is placed too close to the anal opening, the reading will be affected by ambient water temperatures. The standard rectal temeprature of a bottlenose dolphin usually varies between 36 and 37 ℃; the standard rectal temperature of a white whale is usally between 34 and 35℃.

Ultrasound examinations of trained dolphins are conducted while the dolphins station at the surface of the water (Williamson *et al.*, 1990). Handling the trained dolphin in a similar manner, the dolphin's eye can be studied with a close-up magnifying lens and camera. Since the slide photograph can be developed rapidly and projected for precise study, close-up photography with a long lens is a good way to examine the dolphin eye without taking the animal out of the water. Scrutiny of such slides often reveals details not noticed in first-hand examinations.

Although female delphinids have also been trained to give urine samples daily to allow for tracking of reproductive cycles (Walker *et al.*, 1988), blood sampling is still the most prevalent method for assaying reproductive hormones for pregnancy diagnosis (Kirby and Ridgway, 1984; Schroeder, 1990). Since progesterone levels indicative of pregnancy may occur during ovulation as well as during pregnancy, I take three blood samples at two-week intervals; if all three are elevated above five nanograms per ml of serum, I assume that the animal is pregnant. After about three or four months of gestation, the pregnancy can be further confirmed on the stationing animal by listening to the pulsations of the uterine artery with a fetal doppler ultrasound device held on the dolphin's lateral abdomen in line with the trailing edge of the dorsal fin. In the same method, medical ultrasound can also be used to view the development of the fetus (Williamson *et al.*, 1990).

Advances in the study of the anatomy and physiology of delphinid reproduction will facilitate breeding programs for many species of cetaceans. These programs may ensure the survival of some small endangered cetacean species such as the baiji (Ridgway *et al.*, 1989; Zhou, this volume). Many dolhin species have never been under successful long-term human care; therefore, very little is known about their natural history or husbandry requirements. The International Union for Conservation of Nature (IUCN) policy statement on captive breeding (IUCN, 1988) recommends captive breeding populations be initiated while the wild population is still in the thousands. This is one major example of how breeding and rearing cetaceans in human care will have scientific, educational, and in some cases, ecological importance.

With the daily contact between a dolphin and its handler(s) and the advent of petting pools that allow the public to touch dolphins, and of swim programs that allow the public to swim in close contact with the dolphins, the possibility of disease transfer between humans and dolphins has become a matter of concern. An investigation, conducted in the 1960's, considered the possibility of disease transmission to divers and to dolphin handler's and concluded that there was no extraordinary risk (Johnston and Fung, 1969); however, dissections of dead animals and closer associations with live diseased animals have, although rarely, resulted in disease transfer. In fact, *Erysipelothrix* sp., a bacterium responsible for the sometimes fatal erysipelas in cetaceans, has been reported as having been transmitted to people performing post mortem-examinations on animals that have died of the diesease (Nakajima and Takikawa, 1961). Similarly, the fungal pathogens *Blastomyces* sp. (blastomycosis) and *Loboa loboi* (lobomycosis or keloidal blastomycosis) have also been transmitted to humans through contact with infected animals (Cates *et al.*, 1986; Symmers, 1983). These cases underscore the need for precautionary measures during the handling of sick or dead animals and their infected tissues and body fluids. Transmission of disease between healthy dolphins and healthy people is probably not very likely. Precautionary measures that include good water quality, limited access to sick animals, and common-sense hygienic practices employed in responsible husbandry programs will reduce the possibility of disease transfer (Geraci and Ridgway, 1991).

Bottlenose dolphins maintained in a good state of health while in human care have reproduced. Breeding programs for bottlenose dolphins have been successful in many countries; by 1975, over 150 bottlenose dolphins had been born worldwide (Ridgway and Benirschke, 1977). In fact, recent studies comparing demographics and survival rates of wild dolphin populations with dolphin pupulations under the care of humans suggests that reproductive success may be greater for the captive populations (Duffield and Wells, 1990).

In the early history of dolphin care, most of the dolphin breeding occurred in large tanks or enclosures with several adult females and usally just one adult male. When births occurred in the same group, aggression at the time of birth and soon afterward, often occurred (Wood, 1977). Bull dolphins have been found to be aggressive toward each other and sometimes towards mothers and calves (McBride and Hebb, 1948; Essapian, 1963; Wood, 1977; Zeiller, 1977). Possibly as a result of this male aggression and competition between some of the females, there were many stillbirths and calf mortality was high; survival of calves was only about 30% (Wood, 1977). Because these earlier groupings were successful in breeding dolphins, but not in rearing them, new strategies were devised *in some collections*. Pregnant females were moved alone, or with other compatible females, to "nursery" tanks or pens. At Sea World in San Diego, more than 40 pregnancies have been handled in this manner, and a majority of the calves survived to be weaned (Cornell *et al.*, 1987).

I prefer to separate the pregnant female from other dolphins about one month before the birth is due. In our netted bay enclosures, the separated pregnant dolphin remains in visual and acoustic contact with other animals through the netting, even though the animals cannot have direct physical contact. I have observed ten bottlenose dolphin pregnancies managed in this way, with 100% of the offspring surviving past weaning age at two years. I do not know of any other groupings or arrangements that have achieved 100% survival rate. We have not noticed any abnormalities in the offspring or mother dolphins managed in this manner. One female born under this successful management scheme subsequently became pregnant and bore and raised her own calf in this same manner.

At Sea World in San Diego, trainers have been able regularly to collect milk from mother whales that slide out on a special area at the side of their pool. Trainers in our laboratory have perfected a method of collecting milk from a dolphin in the water twice each day. A lactating dolphin is conditioned to present ventrally at the side of the pen, allowing one trainer to support her body weight to keep the mammary slits out of the water. Meanwhile, the other trainer rinses the skin and mammary slit area with distilled water and applies a specially constructed suction cup pump; then, the trainer collects 3 to 25ml of milk rapidly (Fig. 4). The sample is frozen at -70℃ for future analysis. Milk collecion can be used to monitor milk for nutritional value, secretion of medications, and health assessment.

A pregnant female bottlenose dolphin generally increases her food consumption slighly and only toward the end of pregnancy; however, soon after the beginning of lactation, food consumption increases dramatically (Fig. 5). A lactating bottlenose dolphin can consume roughly two to three times as many kilocalories as she did before becoming pregnant or during the first half of pregnancy (Reddy *et al.* 1991).

Calorie consumption, measured in weight of consumed food converted to kilocalories (kcal), was tracked for 10 bottlenose dolphins kept at our San Diego, California facility. Five species of fish and one squid species were purchased in lots and sampled over a thirteen year period for average nutrient content by proximate analysis. Protein and fat content were converted to kcal by figuring conservatively 9 kcal per g for fat and 4 kcal per g for protein. Published values are higher, for example fat=9.3 kcal. We know, however, that digestive efficiency of these nutrients is not 100%; therefore, we use the conservative values. Average values in kcal/kg of food were as follows: Pacific mackerel= 1130 (n=37); Pacific herring=1445 (n=38); Columbia River Smelt=1512 (n=29); squid=692 (n=6); capelin=912 (n=3) and silver smelt=903 (n=9). Seven dolphins in our study were adults and three were immature animals. Data for offspring was tracked from the first fish consumed until the end of the study. In one case, we tracked calorie consumption of a dolphin from her birth in 1979 until she produced her own calf and successfully nursed it in 1991. After weaning at two years of age, young dolphins ate 60 to 120 kcal/kg/da. Mature, non-pregnant dolphins, at relatively constant body weight over periods of more than one year, consumed between 30 and 60kcal/kg/da. For land mammals, basal metabolism is $70 \times$ body $wt.^{0.75}$. On this basis, our average 200kg adult non-pregnant dolphin needed only 3722 kcal/da for basal metabolic needs, but, on average, consumed about 9000 kcal/da or 2.42 × predicted basal (Ridgway *et al.*, 1992).

Our anesthesia methods (Ridgway and McCormick, 1971) have recently been improved. We have induced bottlenose dolphins with an intravenous infusion of an ultra-short acting drug called Propofol (Diprivan, Stuart Pharmaceuticals). This drug was first used in a dolphin at Sea World of Australia. As soon as the dolphin's jaw relaxes, an endotracheal tube is put in place and the lungs ventilated with an isoflurane-oxygen-air gas mixture at a pressure of 15 to 20mmHg. Concentrations of isoflurane vary from 0.5 to 2.0% depend on responses of the animal. During anesthesia, the dolphin's skin is kept moist with a sterile water mist and the electrocardiogram, rectal temperature, and other physiological variables important to the procedure, are monitored.

Application of modern medical knowledge, techniques, and equipment to cetacean medicine requires improved understanding of cetacean anatomy, physiology, and behavior. We now have a great deal of the required knowledge of some genera, such as *Tursiops*. We must continue to learn about all the animals that we keep and those that might ultimately depend on captive breeding programs for species survival. Only through advances in our wisdom, information, and methods can we do the utmost for cetaceans both those in our direct care and those, such as the baiji, that face extinction in the wild.

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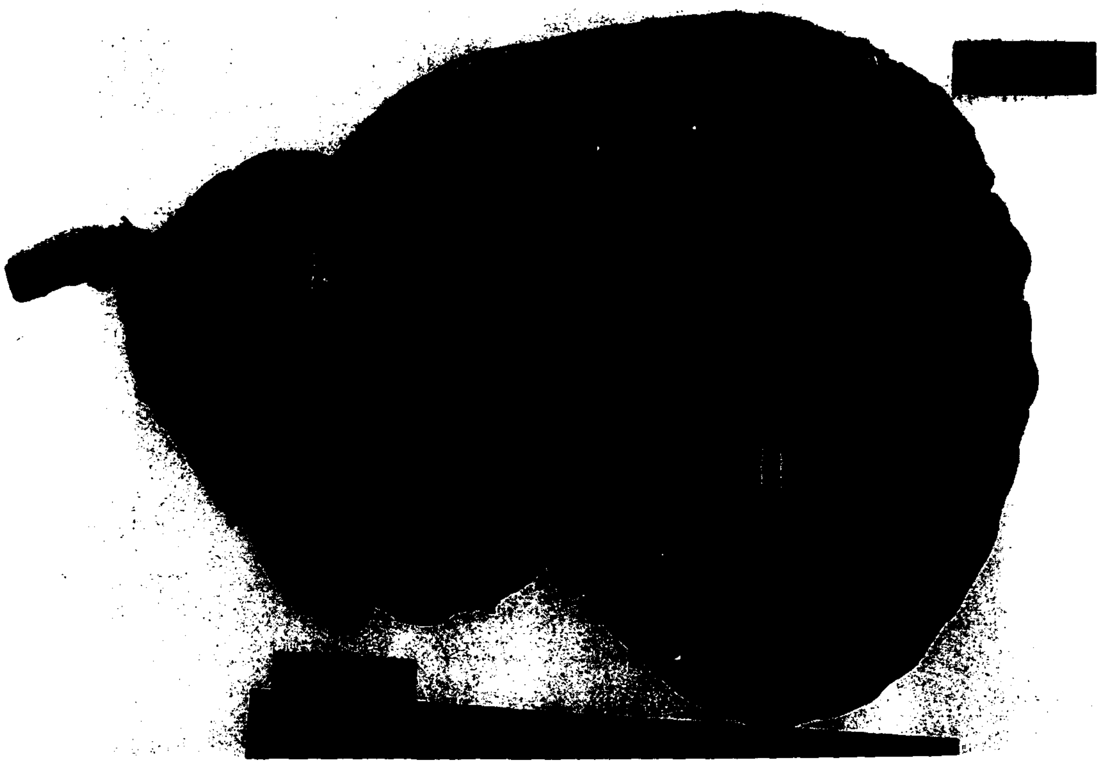

Fig. 1. Mid-line section of a bottlenose dolphin brain. Scale, upper right 0-1 = 1cm. 1 = corpus callosum which is about 30% as large as the corpus callosum from a human brain of similar size. 2 = cerebellum which is about 50% larger than the cerebellum of a human brain of similar size. 3 = paralymbic lobe of the cerebral neocortex, the area between the two deep, almost parallel, sulci. The paralymbic lobe is unique to the br ains of cetaceans.

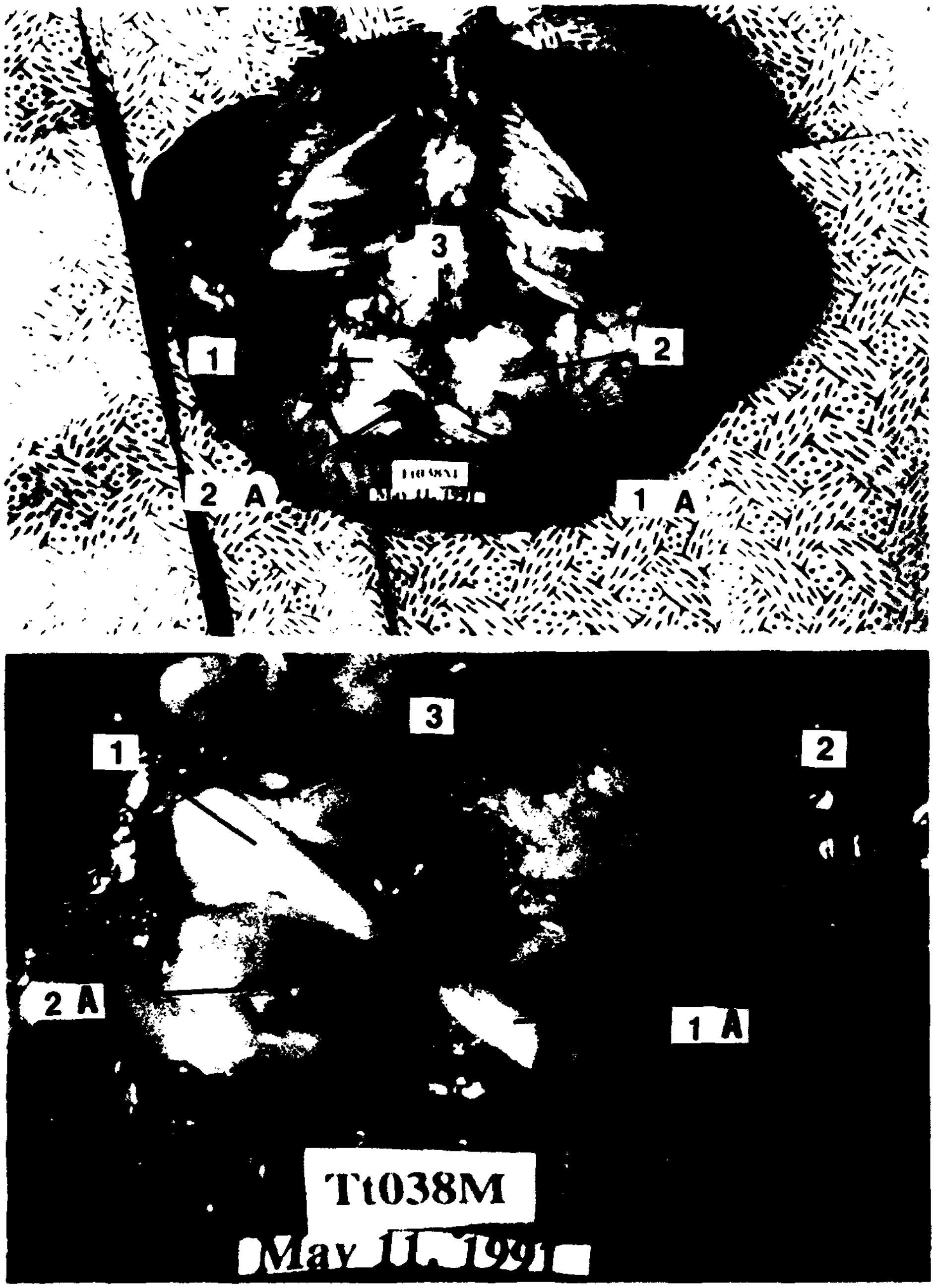


Fig. 2. The ventral surface of a dolphin brain. The animal was blind in its left eye. 1A = normal right optic nerve crossing to become the left optic tract (1). 2A = degenerate, translucent left optic nerve crossing to become the right optic tract (2). This picture supports the complete crossing of each optic nerve at the optic chiasm. 3 = posterior pituitary or neural lobe of the pituitary. The larger anterior lobe of the pituitary has been left in the sella turcica, a depression in the floor of the cranial vault.

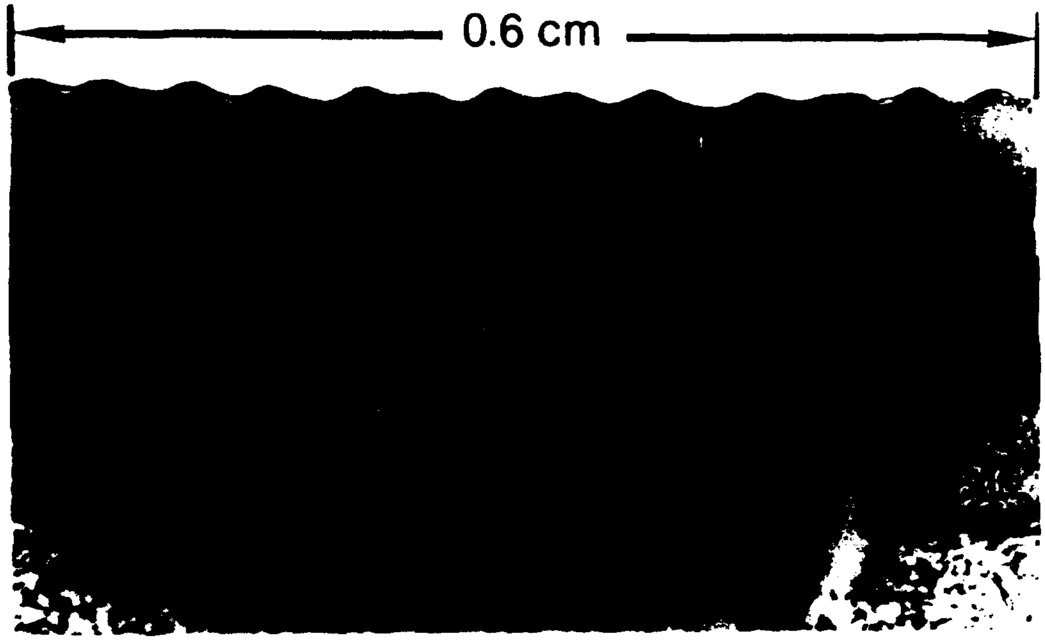


Fig. 3. A microscopic slice through a 0.6cm section dolphin skin showing the cutaneous ridges at the skin surface. The double arrow is parallel to the long axis of the body.

Fig. 4. Mother dolphin presents her mammary area for milking while her calf waits on the surface in front of her.

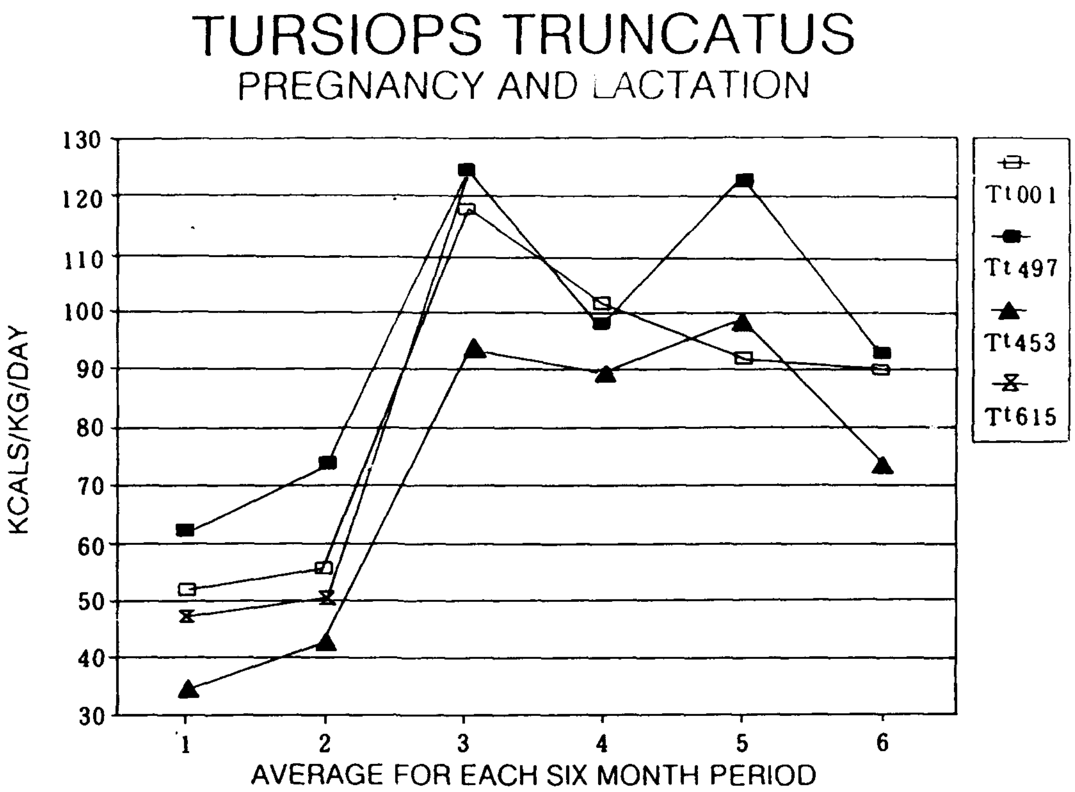


Fig. 5. Change in energy consumption during six 6-month periods from conception through *weaning*: 1, *from conception* to mid-pregnancy; 2, from mid-pregnancy to term; 3, first six month period of lactation; 4, second six month period of lactation; 5, third six month period of lactation; 6, fourth six month period of lactation.